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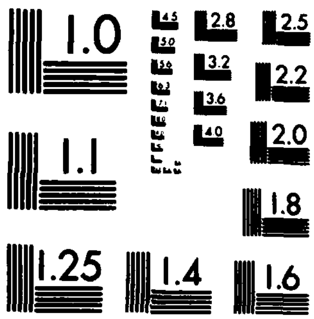

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AN ECONOMIC ANALYSIS OF ALTERNATIVE PAVING MATERIALS

BY
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OREGON STATE UNIVERSITY
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ENGINEERING REPORT
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by

Jennifer L. Mustain

A Project
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AN ECONOMIC ANALYSIS OF ALTERNATIVE PAVING MATERIALS

I. INTRODUCTION

Virtually all road pavements designed today under the auspices of the United States Navy Civil Engineer Corps are asphaltic concrete; little or no consideration is given to using Portland Cement Concrete as a paving material. Yet increases in the cost of asphalt over the last few years, coupled with improvements in concrete paving technology, have caused concrete in many cases to actually be the less expensive paving material in both initial construction as well as life cycle costs.

Given today's economic situation, and the critical eye with which the public and Congress view the military budget, a method of economic analysis along with a program to educate designers in recent material developments is needed in order to ensure that the more economic pavement section is selected, be it asphaltic concrete or Portland Cement Concrete.

The purpose of this paper is to present a means for economic analysis of alternative equivalent pavement designs, considering such factors as initial construction cost, annual maintenance cost, salvage value and the various "intangibles" which occur during the analysis period. Having established a means of economic comparison, it is then the intent of this paper to show that Portland Cement Concrete has been and is a viable pavement alternative and ought to receive due consideration in the military construction program.

II. ANALYSIS METHOD

Several methods have been proposed over the last few decades for determining the cost of highways and road systems. The methods are similar in that all consider a roadway to be a capital investment of funds. The methods differ in the cost factors they consider (aside from the initial cost) to be significant, and in the procedures they use to determine and compare these costs.

Of the basic analysis procedures, one based upon calculation of an equivalent uniform annual cost (EUAC) per mile would seem most appropriate. This method converts over time the main costs -- initial construction, annual maintenance, major resurfacing and salvage value -- into a single cost per year. Comparison of alternatives is made on the basis of the difference in EUAC, the lowest annual cost being the most economic alternative.

To calculate the EUAC, each cost factor is reduced to an equivalent uniform annual cost over the analysis period by use of the appropriate factor: The initial cost is multiplied by a "capital recovery factor"; maintenance costs are typically expressed in terms of annual costs to begin with, but if there is a gradient increase, i.e. perhaps due to the effect of inflation, it may be taken into account by application of a conversion factor; resurfacing costs are usually considered as non-uniform cash flows and are first reduced to present worth and then multiplied by the capital recovery factor to arrive at the EUAC; salvage value represents the terminal value at the end of the analysis period and is reduced to an EUAC by application of a positive sinking fund factor (i.e. a negative

"cost"). Formulas for computing the various conversion factors are shown in Appendix 1.

The equivalent uniform annual cost per mile method is particularly appropriate for Department of Defense projects for several reasons. First, this method, as opposed to say a present worth analysis, is more in tune with the military's annual budget process, and second, annual cost figures developed for the economic comparison of alternatives are relevant and useful in several other planning programs. For example, identifying annual maintenance costs along with the probable time frames for major overlays as part of the initial project evaluation would greatly facilitate preparation of the Public Works maintenance budget as well as promote timely submission of Special Repair Projects, which because of delays in receipt of funds should be submitted one to three years prior to the time repairs are actually needed. In addition, advance identification of required major pavement overlays, rather than waiting until the need for resurfacing has become critical before planning is even started, would significantly help in planning the long range horizontal workload for the Seabees. Identification of annual costs per mile dovetails nicely with Seabee deployment tasking and also facilitates phased funding, which could prove most beneficial at the end of the fiscal year.

In view of the preceding, this paper will utilize equivalent uniform annual cost per mile calculations to compare pavement alternatives for military construction.

III. BASIC COST ANALYSIS FACTORS

In any economic analysis all decisions are between the alternatives; only their differences are relevant. With regard to the selection of paving materials, this focuses our attention predominantly upon costs associated with the traveled way or mainline section. Supervision, inspection and overhead (SIOH) costs for example, will be approximately the same for either alternative and so are not relevant to the analysis. The factors which are relevant are as follows: initial construction cost, annual maintenance cost, resurfacing cost and frequency of resurfacing, salvage value, the analysis period, and finally, the cost of capital which is tied to the interest rate and inflation. The total annual cost may be evaluated by the formula:

$$A = (A/P,\%,Yrs)\left[C_1 + (P/F,\%,Yrs)R\right] + M - S(A/F,\%,Yrs) \qquad (1)$$

Where: (A/P,%,Yrs) is the capital recovery factor, a function of the real interest rate and the analysis period in years.

C_i = Initial Construction Cost

(P/F,%,Yrs) is the present worth factor, a function of the real interest rate and the time in years between initial construction and the resurfacing, or in the case of multiple resurfacings, the time between successive resurfacings.

R = Resurfacing Cost

M = Annual Maintenance Cost

S = Salvage Value

(A/F,%,Yrs) is the sinking fund factor, a function of the real interest rate and the analysis period in years

Initial Construction Cost - This includes construction of the basic roadway and shoulders. Note that identification of separate costs

for the pavement structure and shoulders may make for a more accurate and easier comparison of alternatives. For the analysis presented here, it is assumed that shoulders are unpaved as is generally the case at military installations. Generally, the mile is the preferred unit of measurement for comparison, as the volume of material is a function of pavement thickness.

Annual Maintenance Cost - The annual maintenance cost refers to all road structure maintenance with the exception of major resurfacings; it consists of the routine repairs necessary to keep pavement as close as possible to its newly constructed condition under normal wear and tear. Aside from yearly crack sealing, patching, etc., the Asphalt Institute has found that, on the average, a chip seal is needed every seven years. The cost of the chip seal is commonly included as a routine maintenance cost. Maintenance costs for concrete consist primarily of filling and sealing joints and cracks. Again, maintenance costs should be divided into shoulder and mainline expenses to facilitate comparison of alternatives.

Resurfacing Costs and Frequency of Resurfacing - Resurfacing costs will, of course, vary with the degree of structural repair necessary. Local experience probably provides the best estimate of the amount of structural repairs that will be necessary. With regard to the frequency of resurfacings, estimates of service lives vary. The Asphalt Institute has determined that in general the most economic maintenance program for flexible pavements requires, in addition to yearly routine maintenance and placement of a chip seal every seven

years, a major pavement overlay every 17 years. The Federal Highway Administration, (27), on the other hand, indicated in a report published in 1971 that an average life of 15 years could be expected for flexible pavement before resurfacing would be required. With regard to rigid pavements, the average service life, according to the FHWA, appears to be about 25 years. In comparison, studies by the Portland Cement Association and several state agencies (Oregon - 30 years; Washington - 45 years) indicate that service lives of thirty years or more are common for Portland Cement Concrete pavement.

While most military installations do not have "highways" to build and maintain, their road systems are designed for the most part as major collectors and are subject to heavy industrial traffic. Barring local experience to the contrary, they could be expected to have service lives in the range of those mentioned above. To mitigate any potential industry bias, the FHWA service lives of 25 years for pcc and 15 years for asphalt pavement will be used for the purpose of economic analysis in this paper. The author's experience on bases in Guam and Spain would indicate that this is reasonable.

Salvage Value - There are two reasons for including salvage value in the analysis. The first is that equation (1) is set up to amortize the entire investment in the roadway over the analysis period; yet the last resurfacing may extend the life of the pavement beyond the analysis period. In this case, the salvage value, S_1, is taken as a straight line proportion of the expected life of the

last resurfacing, i.e.,

$$\text{Salvage Value} = S_1 = (1-Y/L)R \qquad (2)$$

Where: Y = number of years between last resurfacing and end of analysis period

L = estimated service life of last resurfacing

R = Resurfacing Cost per mile

In some cases, if a roadway is to be reconstructed the existing pavement may be "recycled", and a salvage value, S_2, attached. For example, asphalt pavement may be scarified, remixed and relaid. Rubble from pcc pavements may also be re-used in other construction and/or stabilization projects. With regard to the Seabees, it has been the author's experience that rubble from pavement projects (both asphalt and concrete) frequently wind up stabilizing an embankment for Special Services, the Navy's morale, welfare and recreation organization.

Period of Analysis - The period of analysis is that period of time over which the economic analysis is being made. The period of analysis should not be confused with either the "design period" or the "life" of the pavement. A pavement may be designed to support traffic for any given period of time; that given period of time is its "design period". At the end of the design period, one may expect the pavement to require major repairs and/or resurfacing if it is to continue to provide an adequate serviceability index. The pavement life may be extended indefinitely through repairs and resurfacing.

There has been considerable discussion as to an appropriate analysis period. The time frame should not be so long as to risk obsolescence due to technological advances or drastic changes in traffic patterns. Too long a period makes prediction of events and costs extremely uncertain. Nor, though, should the analysis period be so short as to miss fully and accurately accounting for major rehabilitation work. Analyses for stateside construction generally use 30 to 40 year periods; whereas the Central Treaty Organization during its seminar on maintenance and improvement of highways recommended an analysis period of not more than 10 years in developing countries. (29)

A 40 year analysis period for military construction within the Continental United States and Hawaii is probably reasonable. Selecting an analysis period for military locations overseas is more difficult. Thirty to forty years is probably reasonable for bases in strong NATO countries, Japan and the Philippine Islands. Twenty years might be more reasonable for countries with soft NATO support and for some of the lesser installations in the Pacific, whereas ten years would seem appropriate for countries such as Bahrain, Kenya, Morocco, Oman, Saudi Arabia and Egypt where U.S. presence is more tenuous.

<u>Cost of Capital</u> - The cost of capital, accounted for by the interest rate used to compute the annual cost factors, allows for consideration of the time value of money. In that the military pays no direct interest per se on the funds it receives, the cost of capital is frequently ignored. This tunnel vision detracts from a realistic

analysis of costs; military construction funds are derived from larger public funds, which if not spent on a given paving job, could potentially be invested to yield a reasonable return elsewhere. This foregone return is represented by the cost of capital and should be included in an economic analysis.

In the past, most highway economic studies have utilized an interest rate of between 5 and 10%, with 6% being the most frequently recommended figure. Given today's interest rates, this would seem low if it is taken as a nominal interest rate. Minimum nominal interest rates of 8% to 15% would appear more realistic.

Inflation Factors - Inflation implies that money loses purchasing power; thus it creates a cost of holding money. This cost should be accounted for as part of the cost of capital. To do so we distinguish between the real rate of interest and the nominal rate of interest, the real rate being the nominal rate of interest minus the rate of inflation.

In an economic analysis comparing two construction alternatives, the relevant rate of interest is the expected real rate of interest, i.e. the established nominal prime interest rate minus the rate of inflation anticipated over the period of analysis.

In these times of economic uncertainty, it is difficult to anticipate rates of inflation, particularly at some of our overseas deployment sites. Fortunately, the task is made somewhat easier by using the Department of the Navy's Annual Pricing Guide which provides anticipated inflation rates for budget years and out years for most all military locations and categories of materials.

<u>The Intangibles</u> - Wherever possible, it is best to reduce factors in the analysis to money units which can be more easily compared. Unfortunately, some of the factors/consequences associated with implementation of a given alternative are difficult to reduce to money terms, yet they do have a bearing on the analysis and should be considered in the decision making process. These "intangibles" or "irreducibles" might include, in the case of alternate pavement materials, smoothness of ride, light reflectability, safety hazards involved with construction, availability of materials locally, local skill level, equipment, experience with materials, etc.

IV. COMPARISON OF ASPHALTIC CONCRETE VS PORTLAND CEMENT CONCRETE

In order to accurately and fairly compare asphaltic concrete and Portland Cement Concrete pavement costs for military construction, this paper will first examine direct cost comparisons for the basic terms in equation (1) and then calculate the resultant annual cost per mile for various interest and inflation rates and depths of pavement. The annual cost per mile for each of the alternatives will then be evaluated in light of the additional "intangible factors".

INITIAL CONSTRUCTION COSTS

Equivalent Designs - For the economic analysis to be relevant, the pavement designs must be essentially equivalent. It would, for example, be irrelevant and misleading to compare an asphalt pavement designed for residential traffic to a concrete pavement designed for heavy industrial use. It should be emphasized here that it is not the intent of this paper to establish what designs are actually equivalent, but rather to provide an economic analysis of designs generally considered to be equivalent within the paving industry. Therefore, for the purpose of this paper, "equivalent designs" are based upon the results of AASHTO tests and are taken from alternative specifications issued by various state and federal agencies. (see Appendix 2) Three equivalent designs will be compared in this paper:

6 inch pcc vs. 8 inch full depth asphalt
7½ inch pcc vs. 10 inch full depth asphalt
9 inch pcc vs. 12 inch full depth asphalt

The Portland Cement Concrete is plain, unreinforced concrete. The AASHTO studies and subsequent studies by several other agencies (PCA, AI, various state highway departments, etc) have shown that reinforcement frequently does not add measurably to pavement performance. Full depth asphalt designs were selected for comparison for several reason: 1) The Asphalt Institute in their latest "Thickness Design Manual" advocates use of full depth asphalt, 2) The thicknesses suggested by the A.I. for full depth asphalt appear to be about the same as those designed by the AASHTO method (except for very light traffic situations), 3) "equivalent" designs for asphalt on granular or cement treated base vary greatly, and 4) studies indicate that full depth asphalt out-performs other flexible pavement designs and may be more economical in the long run. Illustrative of the economic aspect of this is a recent project in Denver where bid sections were 7½ inch thick pcc, 10 inch thick full depth asphalt or 6 inch asphalt on 15 inches of granular base; no bids were received on the asphalt/granular base section. (9) It should be pointed out that even though only pcc and full depth asphalt are being used as examples in this paper, the analysis method presented is equally valid for comparing other pavement designs.

Materials - The following table, taken from FHWA "Federal-Aid Highway Bid Price Indexes" (Engineering News-Record, 27 May 1982), shows the in place material costs for concrete and asphalt over the last few years:

TABLE 1

FEDERAL AID HIGHWAY BID PRICE INDEXES

Year	PCC Price (per SY 9" thick)	Bit. Conc. Price (per ton)
1973	$ 7.00	$10.02
1974	8.88	14.74
1975	8.88	15.13
1976	8.92	14.83
1977	9.95	15.47
1978	11.90	17.16
1979	14.02	21.21
1980	14.92	25.29
1981	14.17	25.63
1982(Q1)	13.63	24.44

To compare the FHWA PCC price to the asphalt price, one needs to ascertain how many square yards of flexible pavement equivalent to 9 inch pcc pavement can be produced from one ton of asphalt.

To do this precisely, one needs to know the number of courses and their thickness in the pavement course, the unit of measure and unit cost of the pay items in the pavement course, and the appropriate multipliers needed to convert the various units of measurement to a square yard-inch unit. Some confusion may arise here as "pay items" for a given section will vary from area to area. For example, in one locale, asphaltic concrete may be separated into asphalt concrete and asphalt cement, while in another it may be grouped into a single lump sum.

To accurately determine the multipliers for the various pay items, the compacted density, or for surface treatments the rate of application, is needed along with the amount of each pay item in the mix - i.e. the percent of asphalt content by weight of mix, the number of gallons per ton of asphalt cement, etc.

Fortunately, several simplifying assumptions may be made with regard to the FHWA table which make calculation of the multipliers quite easy and still keep the economic analysis at a practical level. Under average conditions asphalt plant mix yields roughly 18.18 square yard inches per ton. Thus, to obtain comparable costs on a square yard basis:

$$\text{Cost/Yd}^2 = (\text{price/ton} \div 18.18)(\text{depth in inches}) \qquad (3)$$

Based upon an equivalent design of 12 inch full depth asphalt pavement, the FHWA prices per square yard compare as shown in Table 2.

TABLE 2

Year	9' PCC $/yd.^{2}	12" Full Depth AC
1973	$ 7.00	$ 6.61
1974	8.88	9.73
1975	8.88	10.00
1976	8.92	9.80
1977	9.95	10.20
1978	11.90	11.30
1979	14.02	13.98
1980	14.92	16.65
1981	14.17	16.99
1982(Q1)	13.63	16.13

Converting the 9 inch concrete to 7½ inch concrete and then comparing to the equivalent 10 and 8 inch full depth asphalt, Table 3 results:

TABLE 3

Year	7½ PCC	10" AC	6" PCC	8" AC
1973	$ 5.83	$ 5.51	$ 4.67	$ 4.41
1974	7.40	8.11	5.92	6.49
1975	7.40	8.32	5.92	6.66
1976	7.43	8.16	5.95	6.52
1977	8.29	8.51	6.63	6.81
1978	9.92	9.44	7.83	7.55
1979	11.68	11.77	9.35	9.35
1980	12.43	13.91	9.95	11.13
1981	11.80	14.10	9.45	11.28
1982(Q1)	11.35	13.44	9.09	10.75

It should be pointed out that in arriving at the cost per square yard for nine inch concrete the FHWA had to make simplifying assumptions similar to those recommended here for asphalt. For example, they had to assume a mix design (lbs of cement) for a particular strength concrete as well as the properties/type of aggregate used.

These estimates, both for asphaltic concrete and Portland Cement Concrete, are sufficient for first cut cost estimates and economic analyses.

Looking at the comparative prices of concrete and asphalt per square yard for the various depths given, it may be seen that in 1973 the initial cost of asphalt paving was somewhat less than concrete. Since that time however, the price of asphalt has risen and generally been greater than that of concrete, probably due to the OPEC oil embargo and the continuing concern over future shortages of petroleum products. A drop in prices for both asphalt and concrete is exhibited between years '81 and '82 (first quarter). It is

predicted that this is a short term phenomenon brought on by tight bidding during the present economic slump. Even with excess oil supplies on the market (Engineering News-Record 17 June 1982), the drop in concrete prices was relatively greater than the drop of asphalt prices. Engineering News-Record in their 27 May 1982 issue noted that since the first quarter of 1981, the cost of pcc surfacing was down 9.8% while bituminous concrete dropped 1.2% for the same period. Based upon the foregoing, it would appear that the initial cost of pcc paving is generally less than that of full depth asphalt when compared on a square yard basis for equivalent design.

COMPARATIVE MAINTENANCE COSTS

Routine Maintenance - Routine maintenance costs are extremely difficult to tie down for a comparative analysis. Few agencies keep accurate records of maintenance costs by pavement type. Where costs are broken down by pavement type, it is generally not known whether the roads were or are of equivalent design and are serving similar traffic loads as those they were designed for. Generally speaking, maintenance costs for the pavement are also not separated from roadside repair. The FHWA estimates that in 1976 the total maintenance costs on interstate roads averaged about $7,900 per mile and on all U.S. roads about $3,400 per mile with 20-25% of those figures probably going for actual pavement maintenance and repair. (7)

At least two states have purportedly conducted studies of detailed maintenance costs on their roads. (9) Indiana built test sections of asphalt and concrete on U.S. 51 in 1953. Records kept for 17 years identified average maintenance costs of $68 per mile for concrete vs. $428 per mile for asphalt, exclusive of resurfacing. Oklahoma built a similar test road in 1955 on U.S. 77. Their maintenance records, kept for 20 years, indicated that the costs were $762.00 per mile for concrete and $991.00 per mile for asphalt, exclusive of resurfacing.

A somewhat dated report prepared for the State of Oregon by the Asphalt Institute in 1959 reported average annual maintenance costs of $527 for asphalt and $449 for concrete. (1) At the other end of the spectrum, the Portland Cement Association reports that maintenance costs are four to seven times less for concrete than they are for asphalt. (20)

A more recent study of comparative maintenance costs was prepared by the city of Seattle's Department of Engineering Management and Planning in 1975. (11) The study evaluated alternate types of roadway surfaces in the city, excluding freeways and expressways. Permanent pavement sections being compared consisted primarily of 1) three inch asphaltic concrete pavement on a six inch crushed rock base and 2) six inch Portland Cement Concrete pavement. The annual maintenance costs per mile for a typical roadway width of 25 feet were found to be $425 per mile for the flexible asphalt pavement and $117 per mile for the rigid pcc pavement.

The Navy's Public Works Departments should have records of the "Standing and Specific Job Orders" issued each year to provide for

pavement repairs. Unfortunately, street and road maintenance is easily put off for the sake of more "glamorous" expenditures elsewhere, making annual road maintenance costs appear randomly variable. It is therefore difficult, in spite of an established job order system by which costs could and should be collected, to obtain a sound historical figure for the annual maintenance of station roads.

For lack of a better figure, it is recommended that the City of Seattle's 1975 figures, adjusted for inflation, be used. It is asknowledged that a station road system is not likely to experience the same level of traffic as that of Seattle, nor can it be identically equated with freeways such as those studied by Oklahoma or Indiana. It is also recognized that Seattle's figures are for asphalt on a granular base rather than full depth asphalt. In spite of these shortcomings, Seattle's figures appear to be in an acceptable "intuitive relative range" and exhibit the trend reported in most literature which generally cites concrete as having a lower routine maintenance cost than that of asphalt.

Adjusted for inflation at 7% per year average, the roadway maintenance costs per mile become:

Asphalt	Concrete
$425 in 1975 -- $682 in 1982	$117 in 1974 -- $188 in 1982

As a point of interest the $682 per mile figure is in line with the FHWA estimate that 20-25% of the approximately $3,400 of maintenance funds spent per mile on all U.S. roads goes for actual pavement maintenance and repair. That the maintenance cost presented for asphalt is in line with the FHWA figure is not surprising; the majority

of paved roadways in the U.S. are of asphaltic concrete and would heavily weight the FHWA average for all roads. (Note that since only the differences are relative in a cost analysis, the '75 costs, since they were inflated at the same rate, could have been utilized as they were.) However, for the sake of a uniform cost base year, the projected '82 figures will be used.

RESURFACING COSTS

As mentioned earlier in this paper, resurfacing costs will depend to some extent upon the amount of structural repairs necessary. For the purposes of this paper, it will be assumed that the initial construction was of good quality and that routine annual maintenance was performed and not deferred resulting in the pavement reaching the end of its design life, 15 years for asphaltic concrete and 25 years for Portland Cement Concrete, with only minor structural repairs necessary in conjunction with the major overlay.

The thickness of the overlay is obviously a major factor in resurfacing costs, and will vary depending upon the condition of the existing pavement, projected traffic patterns and type of overlay.

For plain concrete overlays, there are essentially three categories of design based upon the degree of interface or bond between the existing pavement and the overlay:

1) Bonded - completely bonded so that the overlay becomes an integral part of the existing slab

2) Partially Bonded - new overlay placed directly upon existing slab with no attempt to either make or break a bond

3) Unbonded - separated course used to ensure that overlay does not bond to existing pavement; generally thicker than partially bonded overlay and used when base slab is badly deteriorated

A bonded overlay is intended primarily to restore the riding surface and is used when the existing pavement is structurally sound, although some surface distress such as shrinkage cracks, spalling and scaling is allowable. Until recently, the cost of the scarifying and sandblasting operations in preparation for bonded overlays was considered prohibitive. However, with the development of new machines for milling pavement, thin bonded overlays have become more economic. Most thin bonded overlays are two to three inches thick, the overlay thickness being equal to the total thickness minus the original thickness.

The partially bonded overlay also requires that the existing pavement be in fair condition. Overlay thickness in this case is frequently computed based upon the following equation: (7,21)

$$T_o = 1.4 \quad T^{1.4} - CT_e^{1.4} \qquad (4)$$

Where: T = Thickness Required

T_o = Thickness of Overlay

T_e = Thickness of Existing Slab

C = Coefficient reflecting pavement condition

When the existing pavement is in good condition, C=1, (.75 if corner cracks exist) the resulting T_o may be somewhat less than is considered practical; the recommended minimum thickness being five inches for a partially bonded overlay of plain concrete.

Given the assumption that the existing pavement is in fairly good condition structurally, the choice for concrete overlays may be narrowed to bonded or partially bonded. Given the nature and skill level of Seabee operations, it would seem prudent to assume that a

partially bonded 5 inch thick (minimum) plain concrete overlay would be selected for the conditions assumed.

As with concrete, asphalt may be used to correct both surface and structural deficiencies. In the case presented here, where it is assumed that no severe structural deficiencies are evident, the riding surface may be restored by a thin overlay of one to three inches, with a 2½ inch fine grained dense mix overlay being commonly used by Naval stations.

Using 1982 (Q1) prices as reported by the FHWA, the cost of concrete and asphalt overlays compares as follows:

5 inch Concrete Overlay	2½ inch A.C. Overlay
$7.57/SY	$3.36/SY

Note that it is assumed that the overlays will extend the life of the pavement for another 25 years in the case of concrete and 15 years in that of asphalt. In an analysis period of 40 years, this will mean that asphalt pavement will be resurfaced twice, once at 15 years and again at 30 years, and that concrete will be resurfaced once at 25 years.

LIFE CYCLE COSTS

Collecting the individual terms, the total life cycle cost, utilizing 1982 cost data, is calculated by equation 1 for various interest rates, analysis periods, and depths of pavement as shown in Tables 4, 5, and 6. Based upon a life cycle cost analysis, Portland Cement Concrete appears to be the more economical paving material by a considerable margin, if 1982 prices were to continue to prevail. The effect of inflation and risk on projected costs will be discussed later.

TABLE 4

Equivalent Uniform Annual Cost Calculations

$$A = (A/P,i,yrs)\ C_i + (P/F,i,yrs)R + M - S(A/F,i,yrs)$$

Initial Depth of Pavement	Real Interest Rate	C_i/mile	(P/F,i,15;30)	R_1	R_2	(A/P,i,40)	M	S	(A/F,i,40)	A
Full Depth Asphalt										
8 inch	6%	$151,360	.4173; .1741	47,309	47,309	.06646	682	15,770	.00646	$12,499
	8%		.3152; .0994			.08386			.00386	14,060
	10%		.2394; .0573			.10226			.00226	17,559
	12%		.1827; .0334			.12130			.00130	20,261
10 inch	6%	189,240	.4173; .1741	47,309	47,309	.06646	682	15,770	.00646	$15,016
	8%		.3152; .0994			.08386			.00386	18,135
	10%		.2394; .0573			.10226			.00226	21,439
	12%		.1827; .0334			.12130			.00130	24,856
12 inch	6%	227,110	.4173; .1741	47,309	47,309	.06646	682	15,770	.00646	$17,533
	8%		.3152; .0994			.08386			.00386	21,311
	10%		.2394; .0573			.10226			.00226	25,306
	12%		.1827; .0334			.12130			.00130	29,449
Portland Cement Concrete			(P/F,i,25)							
6 inch	6%	127,940	.2330	106,163	--	.06646	188	42,465	.00646	$10,060
	8%		.1460			.08380			.00386	12,044
	10%		.0923			.10226			.00226	14,177
	12%		.0588			.12130			.00130	16,409
7½ inch	6%	159,925	.2330	106,163	--	.06646	188	42,465	.00646	$12,186
	8%		.1460			.08380			.00386	14,735
	10%		.0923			.10226			.00226	16,598
	12%		.0588			.12130			.00130	20,298
9 inch	6%	191,910	.2330	106,163	--	.06646	188	42,465	.00646	$14,312
	8%		.1460			.08380			.00386	17,417
	10%		.0923			.10226			.00226	20,719
	12%		.0588			.12130			.00130	24,169

*assumes two - 12 ft. lanes; FY82 price data

TABLE 5

SUMMARY OF EQUIVALENT UNIFORM ANNUAL COSTS*

		Asphalt EUAC	Concrete EUAC
8" ac vs. 6" pcc	i = 6%	$12,499	$10,060
	8	14,960	12,044
	10	17,559	14,177
	12	20,261	16,409
10" ac vs. 7½" pcc	i = 6%	$15,016	$12,186
	8	18,135	14,735
	10	21,434	16,598
	12	24,856	20,289
12" ac vs. 9" pcc	i = 6%	$17,533	$14,312
	8	21,311	17,417
	10	25,306	20,719
	12	29,449	24,169

*FY82 price data; 40 year analysis period

TABLE 6

EFFECT OF ANALYSIS PERIOD ON EUAC

a) 10 Year Analysis Period, no resurfacing:

		Asphalt EUAC	Concrete EUAC
8" ac vs. 6" pcc	i = 6%	$17,419	$11,747
('82 prices)	8	19,756	13,956
	10	22,150	16,193
	12	24,595	18,457

b) 25 Year Analysis Period, one ac resurfacing, no salvage value for pcc:

8" ac vs. 6" pcc	i = 6%	$13,147	$10,197
('82 prices)	8	15,568	12,173
	10	18,605	14,283
	12	20,714	16,312

Since initial construction as well as maintenance costs of concrete are less than those of asphalt, a change in the analysis period does not change relative result. If initial cost of asphalt were less than concrete, as say in 1978, the lower maintenance cost of concrete coupled with the longer service life still gives concrete a lower annual cost:

c) 10 Year Analysis Period, no resurfacing:

		Asphalt EUAC	Concrete EUAC
8" ac vs. 6" pcc ('78 prices)	i = 6%	$12,437	$ 9,978

If we ignore the salvage value -- in some deployment areas the U.S. might be asked to leave after 10 years, negating any salvage value as far as the U.S. is concerned -- asphalt is marginally less expensive:

8" ac vs. 6" pcc ('78 prices)	i - 6%	$15,125	$15,167

V. THE INTANGIBLES

As stated earlier in this paper, there are some considerations which cannot be reduced to monetary units, yet may have an impact upon the final selection of a paving material. Factors relevant to the study at hand are discussed as follows:

SMOOTHNESS OF RIDE

In the past, the filled expansion joints in concrete pavement gave it a bad reputation for smooth riding. Today, with saw cut joints, this problem has been eliminated. Most measurements of pavement roughness involve at least some degree of subjectivity. Nonetheless, the Present Serviceability Rating developed on the AASHTO road test, as well as various car road-meter tests performed by several states, rate concrete favorably when compared to equivalently designed asphalt over the service life. It might also be pointed out that the higher maintenance costs for asphalt indicate a greater number of patched potholes, which with even the best of repair jobs, do nothing to improve the smoothness of ride.

LIGHT REFLECTABILITY

Concrete reflects light better than asphalt. Although it is difficult to measure, it is logical to conclude that the increased reflectability reduces to some degree the hazards inherent in night driving. This argument could, of course, be turned around to say that concrete increases day time glare. It would seem though that it would be more economical to buy a pair of sunglasses for daytime driving than to increase night time lighting intensities. This issue may be of special relevance to the Navy where the emphasis on "safety

first" is matched in importance by efforts to reduce energy costs, with station lighting being a favorite target for energy conservation.

SAFETY HAZARDS INVOLVED WITH CONSTRUCTION

Concrete is one of the safer building materials. Over the years relatively few workers have developed an illness or suffered an accident attributable to the inherent characteristics of concrete or concrete construction.

Asphalt on the other hand, generally does not enjoy the safety reputation of concrete, and has, in fact, come under the close scrutiny of the Occupational Safety and Health Administration (OSHA) as a potential carcinogen. Specifically, OSHA has put out two publications linking asphalt to cancer: "More than a Paycheck: an Introduction to Occupational Cancer" and "Health Hazards of Roofing Materials: Coal Tar Pitch and Asphalt". Offsetting the OSHA booklets is the National Institute of Occupational Safety and Health's (NIOSH) report that distinguishes between asphalt and coal tar pitch derivatives, stating that there have been no reports of local carcinomas on human skin that can be attributed to asphalt alone, nor have there been reliable reports of malignant tumors of parenchymatous organs due to exposure to asphalt fumes.

It is acknowledged that OSHA has developed a bit of a reputation for creating extreme regulations with sometimes insufficient cause or reasonability. Nonetheless though, the fact remains that the Navy, as part of the federal government, is charged with enforcing OSHA regulations with regard to both its in-house labor force and the civilian construction workers under contract to the Navy. Limited studies aimed at evaluating the exposure of paving workers to asphalt fumes

under normal paving operations indicate that all workers directly involved in the asphalt lay down are exposed to concentrations of total particulates exceeding by a wide margin the limit set by OSHA as a safe exposure to asphalt fumes.

Considering the significant amount of money spent today by the Navy to correct OSHA deficiencies and/or to study the effects of potentially hazardous historic exposures (i.e. the current asbestos studies), the potential safety hazards presently associated with asphalt by OSHA should play at least some part in pavement material selection.

SEABEE SKILLS, EQUIPMENT, AND MATERIAL AVAILABILITY

With the exception of temporary local shortages, paving materials are generally available, for Stateside construction. Unfortunately, the same cannot always be said for overseas deployment sites.

Typically, the Seabees run their own quarry operation and concrete batch plant, using cement shipped in bulk from the States or purchased locally, depending upon the price and availability. Asphalt, on the other hand, is generally purchased from a local vendor, as the Seabees do not typically have the facilities to produce their own plant mix.

The operation of the concrete batch plant provides a degree of flexibility and readiness which is essential to the military. To maintain readiness, Seabees are deployed to various foreign deployment sites and assigned construction projects on which they train their personnel. The limited deployment time may be used most efficiently if the Seabees control their material resources rather than compete for them in a foreign market. The operation of the

concrete batch plant provides this element of control.

The potential problems with external suppliers is brought home by the author's experiences on the U.S. Naval Station in Rota, Spain. There was only one asphalt supplier in the area who, for various reasons, did not hold the Seabees in high regard. As a result, delivery schedules were inexplicably and suddenly changed and the asphalt was more than once of questionable quality. Unfortunately, because of the sole proprietorship and the potential impact upon foreign relations, the Seabees' hands were tied.

In addition to facilitating the control of resources, the batching operation allows the Seabees to train on the "whole" job. It is highly unlikely in the event of a military emergency that the Seabees would find batched concrete or plant mixed asphalt ready and waiting for their construction needs; they must be as self-sufficient as possible in this regard.

A logical question at this point would be "Why not install an asphalt plant?" Asphalt plants have been operated upon occasion by the Seabees, most notably in Diego Garcia. Unfortunately, and owing quite probably to the skill level of the Seabees and their general lack of familiarity with the equipment, these plants exhibited excessive downtime and were a major cause of construction delays and low productivity.

The problems encountered by the Seabees in operating asphalt plants raises the question of Seabee skill level and experience in general. Most of our bases and many of the deployment sites are well established; there simply is not enough new horizontal work (which

because of political considerations must also be shared to some degree with the local civilian contractors), to go around. Because concrete is extensively used in other construction, however, the Seabees are still relatively familiar with the properties of concrete as a construction material and with the operation of the batch plant. In view of the shortage of paving work, even with their own plant the Seabees would not develop the same degree of experience with asphalt as they have with concrete.

To summarize, the Seabees must attain a fair degree of proficiency during peacetime training if they are to accomplish their wartime mission. In the area of paving, this proficiency is best developed through use of concrete: 1) concrete supply and production is more readily controlled by the Seabees, and 2) as it is used extensively in other areas of Seabee construction, it affords maximum exposure to the construction material and batching operations.

Given that most of the young people entering the Seabees today have little or no prior construction experience, and considering the limited deployment time and resources with which the Seabees have to train these people before enlistments are terminated, it would seem that, rather than do two things poorly, the Naval Construction Force would be well advised to concentrate on concrete paving utilizing to the maximum the associated advantages heretofore discussed.

VI. PREFERENCE ANALYSIS OF INTANGIBLES

To place the "intangibles" in proper perspective and to assist the decision maker in assessing both their relative and overall importance, "preference matrix analysis" as suggested by J. L. Riggs in Production Systems, is useful. (25)

FIGURE 1

Ranking the Intangibles

Intangible	A	B	C	D		Sum
A Smoothness of Ride	1	0	0	0	=	1
B Light Reflectability	1	1	0	0	=	2
C Construction Safety	1	1	1	1	=	4
D Seabee Skills, Equip. Mtl	1	1	0	1	=	3
				TOTAL	=	10

In Figure 1, factors are compared by pairs, the preferred, or more important, factor receiving a 1 in its row; the unsuccessful challenger a zero in its column. No preference, as in comparing factor A to factor A, results in a one rating in both column and row. The resultant intangible factor rating is computed by dividing the sum for that factor by the total rating score:

Resultant Intangible Factor Importance Rating, "IFR"

A = 1/10 = .1
B = 2/10 = .2
C = 4/10 = .4
D = 3/10 = .3

FIGURE 2

Rating the Alternatives with regard to each Intangible

Alternative	Factors							
	A	SR	B	SR	C	SR	D	SR
PCC Pavement	1	.5	1	1	1	1	1	1
Asphalt Pavement	1	.5	0	0	0	0	0	0

In Figure 2, the alternative which performs best with regard to the given intangible receives a 1, the unsuccessful challenger a 0; no preference results in a 1 score for both alternatives. The subjective rating, SR, is the number of points received by that alternative for a particular factor divided by the total points for the factor; i.e. with two alternatives, the total points per factor is either one or two; in the case of factor A, where neither alternative was clearly preferred, the SR = 1/2, or .5 for both alternatives.

The Overall Subjective Value for Each Alternative, SV, is given by the following:

$$\sum \left[(I_{FR})(SR)\right] = SV \qquad (5)$$

For PCC Pavement the Subjective Value is then -

(.1)(.5)+(.2)(1)+(.4)(1)+(.3)(1), or .95,

with the Subjective Value for AC pavement being computed by equation (5) as .05.

If we let the cost or objective factors influence 90% of the decision, the impact of the intangibles may be assessed by the following:

$$AR = .9(OF) + .1(SV) \qquad (6)$$

Where: OF = Objective Factor = $\left[(EUAC_{alt.\ i}) \sum_{i=1}^{n} (1/EUAC_i)\right]^{-1}$

AR = Total Rating for given alternative

With the given subjective rating, this results in concrete pavement being selected as the preferred alternative, i.e. greater Alternative Rating or AR, as long as the EUAC (objective factor) is less than or equal to 122% of the EUAC of asphalt paving.

VII. ASSESSING THE UNCERTAINTY

All economic analyses contain a certain amount of uncertainty, particularly if they are projecting costs into the distant future. This element of uncertainty or risk needs to be considered if the analysis is to be complete.

There are methods in use today whereby probabilities are assigned to various cost outcomes and the forecasts of consequences weighted accordingly. There are computer programs available to analyze these various probability combinations, but for a first-cut analysis a subjective evaluation will usually suffice.

For the analysis here there are several "uncertainties" to consider, future maintenance and resurfacing costs, and their relative inflation rates being the most important. If we assume that labor costs in both the concrete and asphalt industries escalate at about the same rate, our risk considerations may be narrowed to the relative escalation/inflation of the material costs.

An examination of the material costs for concrete and asphalt, as published by the FHWA, for 1973 to 1982(Q1), shows that on the average asphalt prices have increased more than those of concrete (see Table 7).

TABLE 7

Year	% Price Increase Over Previous Year	
	Concrete	Asphalt
1974	26.8	47.2
1975	00.0	2.8
1976	0.5	(-2.0)
1977	11.5	4.1
1978	12.0	10.8
1979	17.8	23.7
1980	6.4	19.1
1981	(-5.0)	2.0
1982(Q1)	(-3.8)	(-5.0)

Total % Increase 1982Q1 over 1973: Concrete 94.7% Asphalt 144%

The question is whether or not one can expect this trend to continue. In spite of the increasing interest, and market demand for, "energy independence", the fact remains that the U.S. still relies heavily on foreign petroleum products. That much of the U.S. oil supply comes from third world countries with whom relations are sometimes strained does not portend well for low, stable market prices.

Technology in this instance is both friend and foe of asphalt paving. As alternate energy systems and synfuels are developed, more crude oil will be available for distillation into asphalt. In the interim though, asphalt must compete with gasoline for a share of the available crude. With refiners getting about $1.05/gal. for gasoline and about $.65/gal. for asphalt in 1982, more and more refiners are turning to newly developed technological processes which allow them to squeeze more gasoline from crude oil by breaking down what was previously considered to be the "waste" of the distilling process, that is, asphalt and heavy fuel

oils. The bottom line appears to be that at least for the next few years, the '73 to '82 trend will continue; asphalt prices will tend to increase irregularly and at a greater average rate than other prices in the general economy.

Concrete, on the other hand, is not subject to the same international market forces, and while local shortages may occur which will affect local prices, concrete prices in general can be expected to continue to follow their '73 to '82 trend, keeping pace with the economy in general.

Given that the recent price trends are quite likely to continue for the next several years and recalling that in an analysis of alternatives only differences are relevant, one may utilize 1982 cost data with some degree of confidence that it will produce "relatively" accurate results. Maintenance costs need not be escalated as they should be largely determined by labor costs which we said earlier would inflate at about the same rate for asphalt as for concrete repair work. As far as the resurfacing costs go, one may wish to inflate the asphalt material cost a few percentage points above that for concrete to reflect the trend of greater rate of increase in price. For the majority of the cases presented here, concrete is decidedly the more economic paving material; escalating the asphaltic concrete material price for the overlays would only increase the economic advantage of Portland Cement Concrete over that of asphalt.

CONCLUSION

Given today's economic situation and the degree to which every tax dollar must be stretched, it is important that military construction planners be aware of recent market trends and that they use available economic tools to ensure that construction funds are utilized as efficiently as possible. To this end, the preceeding pages have presented a method of economic analysis and have shown that in so far as paving is concerned:

1) Concrete is an economic paving material; initial construction costs as well as total life cycle costs are <u>less</u> expensive for concrete than for equivalently designed asphalt pavement.

2) With regard to the intangible factors, concrete clearly out-performs asphalt as a paving material. Allowing the intangibles to influence 10% of the material selection decision results in concrete being the preferred alternative even when its life cycle costs exceed those of asphalt by 20%.

3) The material selection decision is not "interest rate sensitive". With today's market prices, there is no positive interest rate that would promote asphalt to being the preferred alternative.

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APPENDICES

APPENDIX 1

Functional Symbols and Interest Formula Equations

Symbols

i = interest rate per interest period

n = number of interest periods

P = Present Sum of Money

F = Future Sum of Money at end of n periods from present that is equivalent to P given an interest rate i.

A = Annuity Amount received or paid at the end of a period in a uniform series of n periods, where the total series is equivalent to P at an interest rate of i.

Formulas

Compound Amount Factor = (F/P, i%,n) = $(1+i)^n$

Present Worth Factor = (P/F,i%,n) = $\dfrac{1}{(1+i)^n}$

Sinking Fund Factor = (A/F,i%,n) = $\dfrac{i}{(1+i)^n-1}$

Capital Recovery Factor = (A/P, i%,n) = $\dfrac{i(1+i)^n}{(1+i)^n-1}$

Uniform Series Compound Amount Factor = (F/A,i%,n) = $\dfrac{(1+i)^n-1}{i}$

Uniform Series Present Worth Factor = (P/A,i%,n) = $\dfrac{(1+i)^n-1}{i(1+i)^n}$

APPENDIX 2

Equivalent Design Depths

Traffic Category	Subgrade Classification: Very Good — Full Depth Asphalt	Very Good — Portland Cement Concrete	Good — Full Depth Asphalt	Good — Portland Cement Concrete	Poor — Full Depth Asphalt	Poor — Portland Cement Concrete
Freeways	8 in.	6 in.	11 in.	8 in.	16 in.	10 in.
Major Arterial, Local Business or Industrial St.	7	6	9	7	13	9
Collector Street	6	6	8	6	11	8
Local Residential Street	5	5	6	6	8	6
Residential Driveways	4	5	5	5	7	6

The above table is taken from the "Handbook of Highway Engineering" edited by R. F. Baker (1975). The author's note that the thicknesses presented will "generally provide for reasonable estimates of cost and general requirements".

Most alternate specifications investigated during research for this paper were in line with the recommendations of this table although local conditions and experience have resulted in nominal differences, i.e. 7½" pcc versus 10" ac (Denver), 6" pcc versus 9" ac (Clackamas County, Hillsboro). Common standard for cost comparison using ASSHTO Interim Design Guide is 12" ac versus 9" pcc, although PCC claims 14" ac is really required to achieve same safety margin as that provided by 9" pcc. It might also be noted that the Asphalt Institute is currently recommending 4" as the minimum depth for full depth asphalt, which is in line with the table here. The 5" pcc section recommended for Residential Driveways may be slightly excessive, 3" and 4" having been constructed and utilized with success.

APPENDIX 3

PROJECTS BID WITH BOTH
ASPHALT AND CONCRETE ALTERNATES
FEBRUARY, 1980
CITY OF CORVALLIS

PROJECT	YEAR	SQUARE YARDS CONCRETE	SQUARE YARDS ASPHALT	TOTAL
S.E. PARK AVENUE	78-79	8,850		8,850
SW TWIN OAKS	78-79	950		950
BUTTERFIELD STATION	78-79		8,165	8,165
WALNUT PARK PHASE I	78-79	11,314		11,314
WALNUT WEST	78-79	6,446		6,446
WITHAM WEST	78-79	4,750		4,750
WAKE ROBIN	78-79		4,750	4,750
8TH STREET	79-80		1,400	1,400
GROVE STREET	79-80		1,350	1,350
MAYBERRY AVENUE	79-80		3,100	3,100
DEBORD STREET	79-80		1,680	1,680
CREEDMORE	79-80		5,157	5,157
FOREST HEIGHTS 2ND	79-80		6,700	6,700
WALNUT PARK PHASE II	79-80	23,315		23,315
TOTAL		55,625	32,302	87,927
% OF TOTAL		63%	37%	

[illegible]